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GEOMETRY LABORATORY (GEOLAB) SURFACE MODELING AND  
GRID GENERATION TECHNOLOGY AND SERVICES

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## Abstract

The facilities and services of the GEOMETRY LABORATORY (GEOLAB) at the NASA Langley Research Center are described. Included in this description are the laboratory functions, the surface modeling and grid generation technologies used in the laboratory, and examples of the tasks performed in the laboratory.

## 1 Introduction

Discussion of the concept of GEOLAB began in the late 1980s when computational fluid dynamics had demonstrated the capability to produce accurate and relatively inexpensive flow fields about complex geometries. The bottleneck for obtaining solutions, however, was the amount of time required to prepare the surface geometry and grid data for the flow field solvers. Typically, several months of intense activity was required to produce geometry data after which the first flow field solution could be obtained in a matter of hours. A similar amount of time was required each time a new configuration was undertaken. Computer-Aided Design (CAD) software and emerging grid-generation software potentially could increase the surface and grid data productivity, but it had to be organized and integrated into the overall computational environment. The concept of GEOLAB was to centralize those geometry activities requiring specialized (but broadly applicable over many disciplines and organizations) talents, software, and hardware and to decentralize those tasks which required individual engineering tuning. Training and communications were, and still are, the essential ingredients for the concept.

GEOLAB was initially formed in 1990 to support Langley researchers performing Computational Fluid Dynamics (CFD) analyses. GEOLAB focuses on high performance workstation hardware, CAD and grid generation software, and the skills to efficiently produce geometry data. The main goals of GEOLAB are to improve the efficiency in performing geometry related functions such as surface modeling and grid generation, to promote technology development of new geometry techniques, and the transfer of such development to customers both internal and external to the Langley Research Center. In the past four years, GEOLAB has expanded its capabilities in order to support projects involving conceptual design, model production, structural analyses, materials, multi-disciplinary optimization, and

reverse engineering.

Since its inception GEOLAB has reduced the time to perform a surface modeling and grid generation task defining a volume grid of a full aircraft complete with tail surfaces, fillets, pylons and engine nacelles from 6 months to 2 weeks. In addition, this also represents an approximate "order of magnitude" decrease in the cost of grid generation for a detailed Navier Stokes CFD analysis in a typical project.

## 2 GEOLAB Resources

GEOLAB is equipped with state-of-the-art hardware and software. The hardware includes 10 high-end Silicon Graphics workstations and 7 NCD X-terminals. The workstation consoles are located in a communal area near desk space where the X-terminals are located. A CYBERWARE laser digitizer and a Calcomp Flatbed Digitizer are also available in GEOLAB to enable mathematical surface reconstruction from physical objects and blueprints. The equipment is used primarily for the production of surface models, computational grids, and for software development; users must be involved in surface modeling or grid generation projects to qualify for accounts and use the equipment during prime hours. In addition, researchers working on parallel algorithms are given accounts in order to test their algorithms in a clustered workstation environment during non-prime hours. There are over 75 users including the GEOLAB team.

The GEOLAB software includes CAD, grid generation, and visualization tools that have been developed or acquired to facilitate the generation and analysis of surface representations, surface grids, and volume grids for both structured and unstructured analysis techniques. Among the tools currently in use in GEOLAB are: GRIDGEN, ICEMCFD, VGRID, GridTool, CSCMDO, SurfACe, SCAFFOLD, and VOLUME. Each of these software tools is briefly summarized in Appendix A.

A key element to productivity and efficiency in GEOLAB is the integrated computing environment provided by the system administration techniques employed. All user files and software files are cross-mounted so that all utilities are available on all machines. Network licenses are purchased when buying commercial software so that no workstation needs to be reserved for a particular function. Passwords are common across the machines. Access to general-purpose tools and utilities such as printers, manual pages, electronic mail, editors, etc. are available from any machine. An attempt is made to keep the workstations at the same revision of the operating system and to keep the amount of memory and CPU type uniform across the cluster. In general, the user is presented with the same environment and resources transparently, no matter which workstation is used.

The hardware and software are matched with a team of skilled specialists consisting of 5 civil servants, a National Research Council fellow, a university post doctorate, two university

civil servants, a National Research Council fellow, a university post doctorate, two university doctoral candidates, and 7 non-personal services (NPS) contractors. The members of the team have mechanical or aerospace engineering, computer science, and mathematics backgrounds. The contractor team members are responsible for performing most of the surface modeling and grid generation tasks in response to the Research and Technology Group at Langley and other external organizations. Also they are heavily involved in the development of specialized software tools that are needed to improve the efficiency of the process or to provide a custom tool to support a research project initiated in the Research and Technology Group at Langley. The civil service personnel are involved in the development of new methodologies for surface modeling and grid generation, data transfer and computing environment issues, and the administration of GEOLAB. While the expertise of team members lies in different specialty areas, most are cross-trained in all the software tools used in the laboratory in order to maintain a cohesive and flexible response to customers.

GEOLAB is currently located in the Scientific Applications Branch of the Information Systems Division, Internal Operations Group at the NASA Langley Research Center. The GEOLAB team has access to advanced tools for scientific data visualization, data base management, image processing, and high performance computing as a part of the Scientific Applications Branch. In addition, the team has ready access to other services within the Internal Operations Group that support wind tunnel model production and experimental testing. The availability of these capabilities greatly enhance both the scope of problems GEOLAB is able to address and the quality of the resulting work performed in GEOLAB.

### **3 GEOLAB Functions and Experiences**

GEOLAB functions can be divided into 4 categories: (1) production surface modeling and grid generation tasks; (2) software development supporting surface modeling and grid generation; (3) research into new technology; and (4) training and technology transfer.

#### **3.1 Surface Modeling and Grid Generation Tasks**

GEOLAB performs a wide variety of production surface modeling and grid generation tasks enabling researchers to effectively proceed with their computational analyses. The details of these tasks include data repair such as adding missing features; blending features together; and reconstructing surface models from grid points, blueprints, or measurement of existing physical models. Other tasks include preparation of surface and grid data for parametric studies and production of denser or sparser grid sets.

Most production surface modeling and grid generation tasks take 2 to 6 weeks to complete depending on the complexity of the configuration, the accuracy required to support the intended analysis tool, the nature and condition of the input data, and the format of the

output data. Projects in which the input data is not in electronic format, i.e., coefficients or points in a design book, blueprints, or models for which a high degree of accuracy is needed to support Navier-Stokes analysis, may take 6 to 12 months to complete. Usually these projects are only undertaken if several groups of researchers have need for the data. GEOLAB also provides support for much smaller tasks such as data conversion, geometry visualization, and quick data verification for researchers. These tasks usually require anywhere from an hour to 3 days. Tool development tasks require anywhere from 2 to 12 months development time. The tasks are usually broken down into sub-tasks with specific deliverables and schedule. The researcher is involved at an early stage as the requirements are decided upon and as each major subsection is developed and demonstrated. This involvement also provides several points at which priorities may be re-assessed and adjusted.

## 3.2 Software Development

The software used in GEOLAB is licensed from commercial companies, obtained free from government sponsored development projects, or created in-house. The choice of which source to use is based on availability, cost and timeliness. CAD software, as a rule, is always licensed. Grid generation software is usually acquired from freeware sources or created in-house. Special purpose software is almost always created in-house. The programs SurfACe, GridTool, SCAFFOLD, and CSCMDO described in Appendix A are representative of the software developed in GEOLAB. The rationale for creating them in-house follows.

SurfACe (Fig. 1) is a software package used to evaluate the quality of surface grids. It allows visualization of the surface of multi-component configurations and the characterization of several grid quality functions on the surface. Since SurfACe is tailored to evaluate surface grid quality, it has been designed to expedite these operations. This gives SurfACe its primary advantage over systems such as FAST, a freeware visualization system or FIELD-VIEW, a commercial visualization system.

GridTool (Fig. 2) is a surface grid generation program originally written to prepare unstructured surface grids for the VGRID unstructured volume grid generation system. GridTool has evolved to be a versatile utility bridging the gap between CAD geometry and grid generation programs. GridTool creates grids on patches that are projected to the CAD description, thereby easily generating grids that are on the precise CAD description of the surface.

SCAFFOLD (Fig. 3) is an interactive program written to recreate numerical geometry models from measured data obtained by scanning physical models with the CYBERWARE laser digitizer. SCAFFOLD provides the bridge between measured models and CAD models. It is an example of the specific software developed in GEOLAB to meet a specialized need across many organizations.

CSCMDO (Coordinate and Sensitivity Calculator for Multidisciplinary Design) (Fig. 4)

is an automatic volume grid generator that operates in a batch environment in conjunction with a shape optimization process. It is based on being given a surface grid for a high-speed civil transport configuration and an initial volume grid possibly generated with software such as GRIDGEN or ICEMCFD. CSCMDO automatically adjusts the volume grid to small changes in the shape of the configuration surface. Large changes in the surface shape, topology or number of surface grid points require a new volume grid from another source. CSCMDO was developed at the request of the Multidisciplinary Design and Optimization Branch of the Langley Research and Technology Group.

### **3.3 New Techniques for Surface Modeling and Grid Generation**

The establishment of GEOLAB was based on many prior years of grid generation research in the Analysis and Computation Division at the Langley Research Center (LaRC). The development of new techniques is now an integral part of GEOLAB. There are two in-house project under way: (1) The rapid generation of airplane configurations using engineering parameters, and (2) The development of high aspect ratio unstructured grid generation techniques. Appendix B presents a short description of each of these projects.

## **4 Training and Technology Transfer**

Besides surface modeling and grid generation tasks, GEOLAB also provides training in the software tools used in the lab. The tools may be commercial software or they may have been developed under contract for NASA to researchers at LaRC, other NASA centers, government agencies or industrial partners. Included in the list of tools supported to this extent are: GRIDGEN, ICEMCFD, GridTool, and CSCMDO. GEOLAB presents two grid generation classes a year on elements of grid generation, the use of GRIDGEN for structured grids, and the use of VGRID for unstructured grids. These classes include hands-on tutorials. During these sessions GEOLAB is dedicated to the training class to allow the participants access to the hardware. The lab environment is ideal for this type of activity with 10 machines in one area and easy access for the instructor. One-on-one training is provided on request in the use of specialized tools like SurfACe, GridTool, and CSCMDO. Over 200 people have been trained by GEOLAB since its inception.

GEOLAB is committed to technology transfer to the Langley researchers, other government and university centers, and U. S. industry. In addition to offering training, GEOLAB makes available its non-proprietary software tools upon request. By far, the most requested software is GridTool. At this writing, 80 copies have been distributed throughout the United States, in addition to its use at Langley.

Cooperative Agreements between GEOLAB and outside organizations can be made to produce surface models and grids. GEOLAB staff will demonstrate the software tools and

methodologies on geometry problems of interest to the requester. Agreements of this nature have been entered into with David Taylor Research Labs, Boeing Company, McDonnell Douglas Corporation, and Ford Motor Company. These agreements are normally coordinated through the Technology Applications Group (TAG) at Langley

## 5 Data Management and Communications

Data Management and Communications are an extremely important aspects of GEOLAB. Surface geometry is normally communicated in Initial Graphics Exchange Specification (IGES) or NASA-IGES (NIGES) files. This standard formatting of surface data allows rapid interaction with customers, both government and industrial, for surface geometry problems. Langley Wing Geometry Standard (LaWGS) and PLOT3D files are also used.

A data management system called PRISM is used to manage large quantities of data pertaining to a given project. PRISM arose out of the High Speed Airplane Integrated Research (HiSAIR) study and is comprised of a Graphical User Interface (GUI) and a software interface to a Database Management System (DBMS). The PRISM GUI uses the X Windows System and the Motif toolkit to provide a window based "point-and-Click" interface. PRISM used the commercially available Informix DBMS with a Sun SPARCstation currently functioning as the database server. The PRISM software provides for automatic searching or querying for particular data sets (or subsets) to the user's workstation, storing new data sets, and an administrative/security mechanism controlling access to shared databases.

## 6 Future Directions

There are several problem areas that GEOLAB would like to address in the future. The most important is the length of time it currently takes to produce a surface representation and computational grid for analysis. As was stated earlier, it usually takes 2-6 weeks to prepare the geometry and volume grid for a detailed Navier-Stokes analysis. To meet the needs of industry, this time must be reduced to hours. To meet this need, better tools are needed to run in a more automatic fashion with little or no human intervention. In addition, these tools must also be flexible and robust enough to handle computations dealing with a high degree of complexity.

Further work is indicated in other specific areas in which GEOLAB is currently involved. More diagnostic tools are required to guarantee that any given computational grid is satisfactory, thereby reducing the number of revisions needed to allow accurate modeling of the physical processes being studied. These tools need to be developed for computational structural mechanics problems as well as for computational fluid dynamics problems. Additional work is needed in the area of unstructured grids in order to allow the generation of un-

structured grids to handle viscous flows. Further work in the area of parameterizing surfaces with respect to design variables is needed to shorten the design and preliminary design cycles.

In addition, expansion of effort in other areas is indicated. New advances in the area of reverse engineering are to be studied. New techniques to relate 2-D CT scans to an accurate 3-D surface representation of a model or structural element are needed. Also, more robust algorithms for surface reconstruction from point clouds measured from laser digitizers are needed. More experience is needed within the GEOLAB team to become more familiar with grids for structural analysis.

As the team works to solve individual task requests, new tools are being generated and existing tools are being improved to increase the efficiency of all aspects of the grid generation process.

## 7 Conclusions

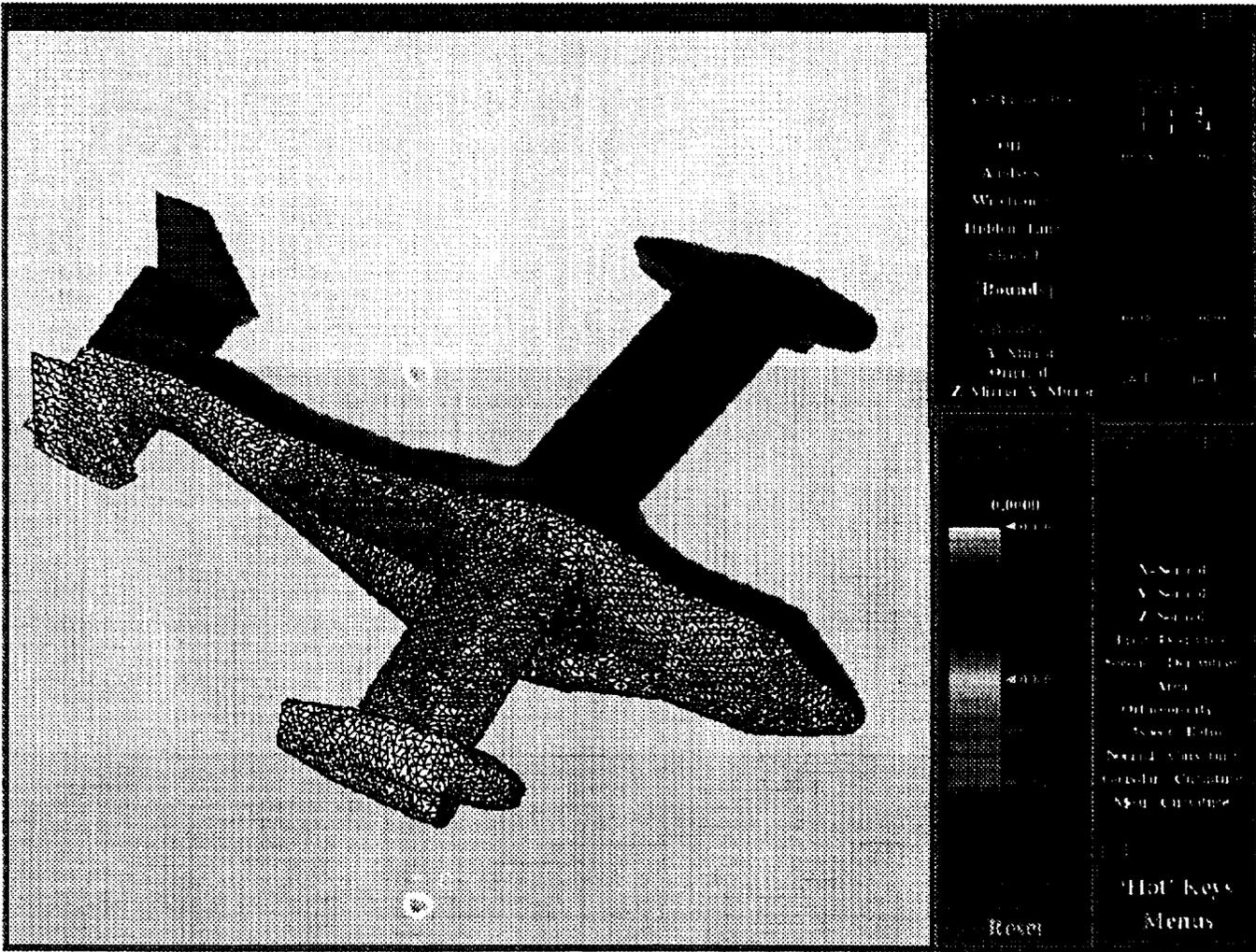
GEOLAB has become the focal point for geometry issues at Langley. It is providing an essential function for all continuum simulation in a cost effective manner. Researchers do not need to be geometry experts in order to accomplish their mission. GEOLAB has become an interface between Langley Research Center organizations and their customers to allow rapid interchange and use of geometry data. GEOLAB is developing new technology for surface modeling and grid generation, and in addition to using the technology in-house, is transferring it to other NASA, government, university, and industrial organizations.

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Figure 1: An unstructured surface grid for the V22 Osprey is shown in SurfACe along with a shaded representation of the surface geometry.



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Figure 2: The surface geometry for the Apache helicopter is shown in GridTool with several patch boundaries and point distributions defined prior to projection to the surfaces.

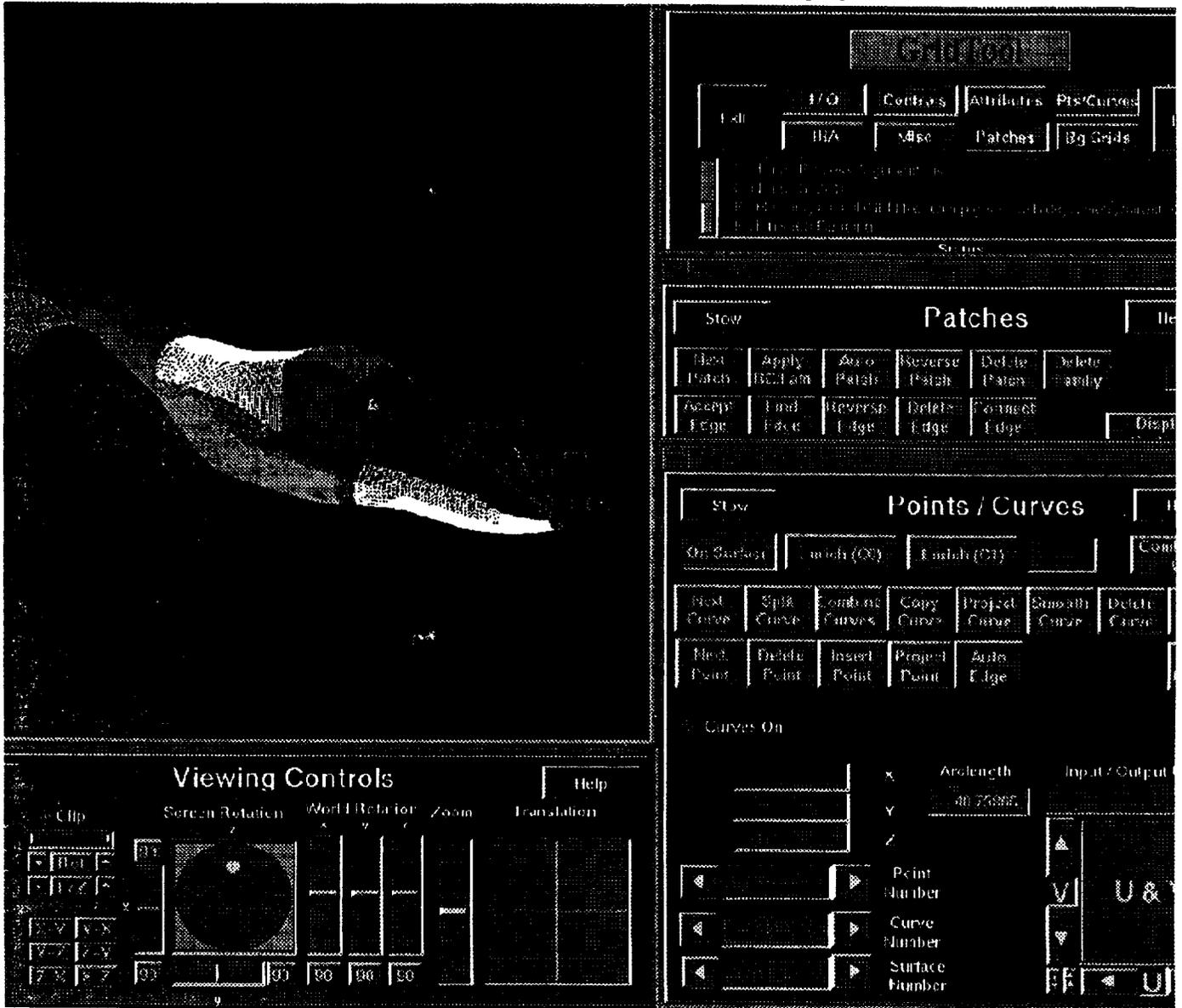
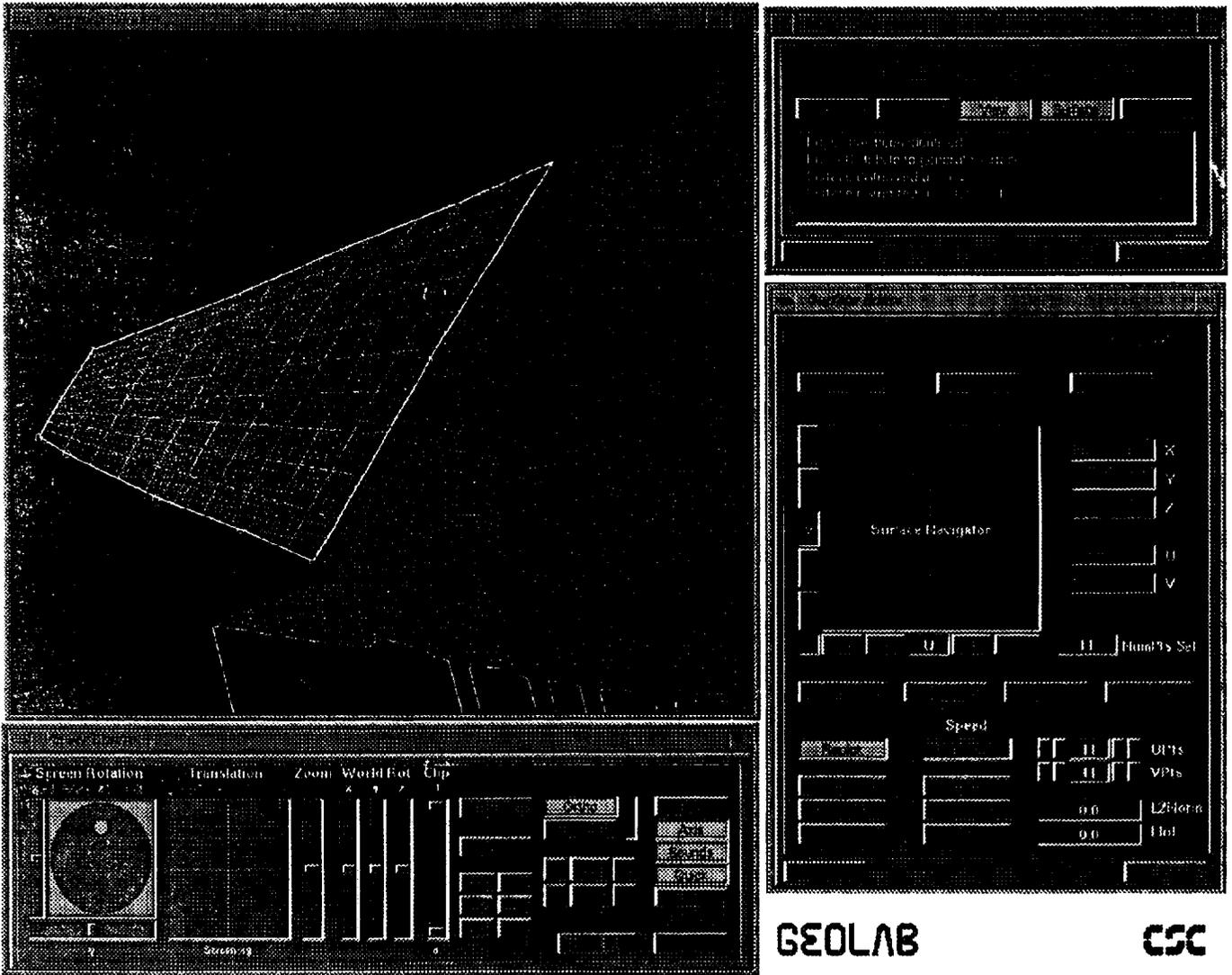


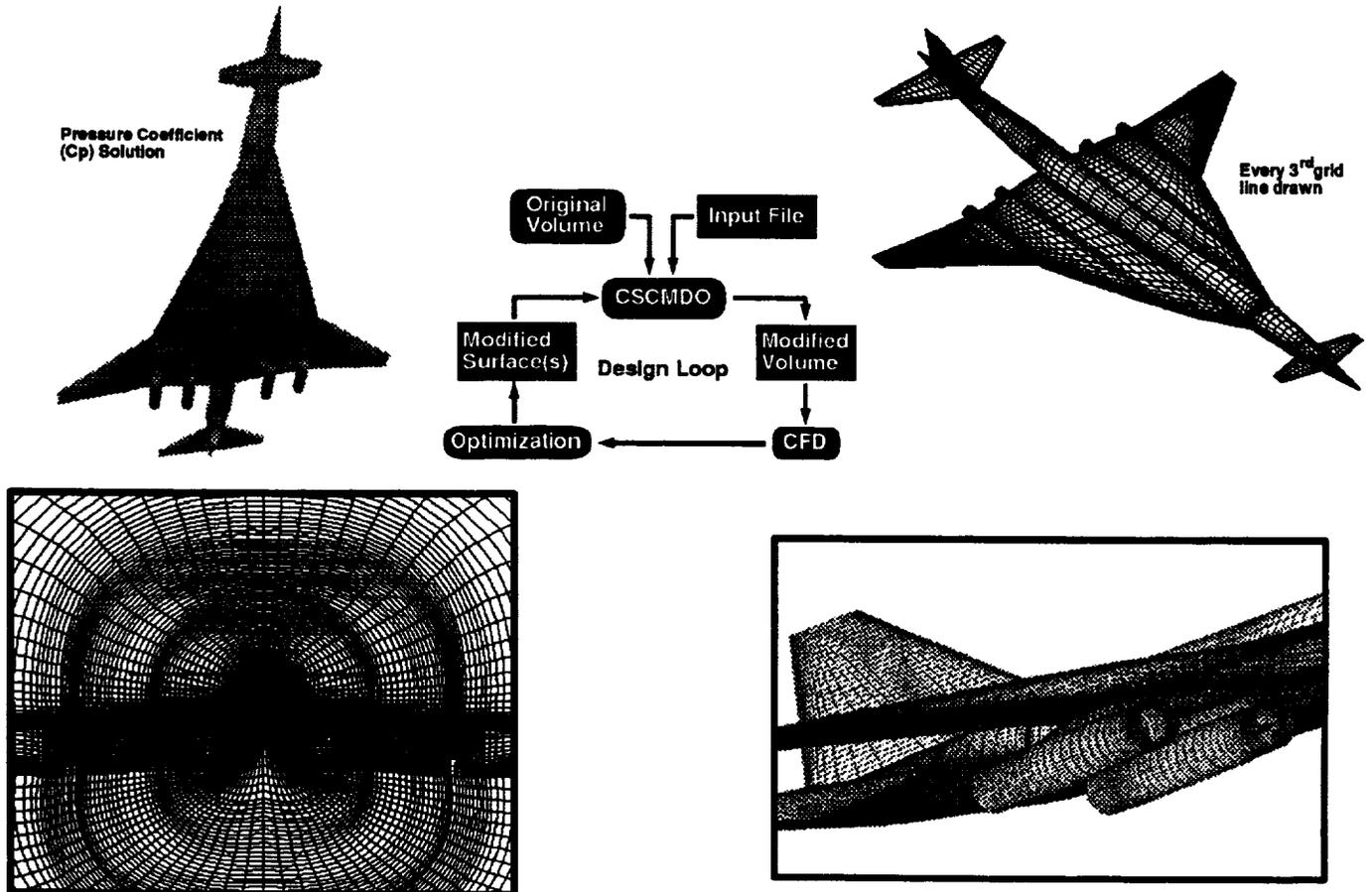
Figure 3: The measured points from the wing of an F-22 model is shown along with the newly fitted mathematical surface in the SCAFFOLD program.



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Figure 4: The integration of the CSCMDO program into the design loop is shown

## Coordinate and Sensitivity Calculator for Multi-Disciplinary Design Optimization (CSCMDO)



## A Software Tool Summary

GEOLAB uses a variety of software for surface modeling, grid generation, and flow field validation of geometry. The purpose of the Appendix is to give the reader an overview of the software. The Commercial packages are:

- GRIDGEN
- ICEMCFD
- AZ2000/AZ3000
- PATRAN

Tools developed in GEOLAB available to the U.S. Government, Universities, and Industry are:

- CONVERT
- CSCMDO
- GridTool
- SCAFFOLD
- SurfACe
- VOLUME

Tools developed at Langley or other NASA facilities and available to the U.S. Government, Universities, and Industry are:

- VGRID/USM3D
- TLNS3DMB
- CFL3D

### A.1 GRIDGEN

GRIDGEN version 8 is a system of four codes for the generation of 3D, multiple block, structured grids: GRIDGEN version 8 was developed by MDA Corporation and sponsored by the Langley Research Center. The four programs are:

GRIDBLOCK is an interactive code for decomposition of the domain of interest into blocks, distribution of points along edges, and algebraic surface grid generation.

GRIDGEN2D is an interactive code for elliptic PDE refinement of 3D surface grids on the six faces of each block in the system.

GRIDGEN3D is a batch code for the generation of 3D volume grids on the interior of each block in the system.

GRIDVUE3D: Interactive code for inspecting volume grids.

The three interactive codes have been written using the Silicon Graphics IrisGL graphics library for both the user interface (e.g., buttons, text input) and the grid rendering. As such, these codes will only run on hardware that supports IrisGL. Version 8.3 of Gridblock, Version 8.4 of Gridgen2d, Version 8.8 of Gridgen3d, and Version 8.6 of Gridvue3d are currently available.

GRIDGEN version 9 integrates the functions of GRIDBLOCK and GRIDGEN2D into a single interactive program. GRIDGEN version 9 was developed by MDA corporation and sponsored by the AMES Research Center. GRIDGEN version 9 is available from COSMIC.

## **A.2 ICEMCFD**

ICEMCFD is a grid generation system built on top of a full CAD system. Geometry data can either be created within the system or read as either point format or IGES format. The grid is created independent of the geometry and at the end of the process projected directly onto the CAD surface geometry. This patch-independent approach can overlook small gaps and overlaps of the surfaces in the geometry.

ICEMCFD can be used to produce multi-block structured grids, unstructured tetrahedral grids, and body-fitted Cartesian grids. The resulting grids, topology and boundary conditions can be output in a number of formats to match different flow solvers that may be used.

## **A.3 AZ2000/AZ3000**

AZ2000/AZ3000 are software packages developed by Program Development Corporation for generating and displaying two and three dimensional multiblock structured grids. The packages automatically determine the blocking structure around complex geometries and accommodate nested grids. One license for the 3D 500 block, 1 million grid point code has been purchased, for assessment of code capabilities.

## **A.4 PATRAN**

P3/PATRAN is a general purpose three-dimensional Mechanical Computer-Aided Engineering(MCAE) software developed by PDA Engineering. P3/PATRAN provides a graphical environment where geometry can be modeled and pre-processed for analysis; the analysis results can be post-processed within the P3/PATRAN environment. It allows direct access to geometry from CAD systems such as Unigraphics, Pro/ENGINEER, and CATIA or as Initial Graphics Exchange Specification(IGES) entities. It also provides analysis preferences for code specific data input for analysis codes such as ABAQUS, ANSYS, MARC, and MSC/NASTRAN.

## **A.5 CONVERT**

CONVERT is a batch program that allows one to convert grids to/from various formats such as binary, formatted, unformatted, single precision, double precision, PLOT3D, GRIDGEN, LaWGS, Tecplot, etc.

## **A.6 CSCMDO**

CSCMDO is a general multi-block three dimensional volume generator suitable for multidisciplinary design optimization. The code is highly automated, robust, and efficient. Algebraic techniques are used to generate and/or modify block face and volume grids to reflect geometric changes resulting from design optimization. Volume grids are generated/modified in a batch environment and controlled via an ASCII user input "deck". This allows the code to be used directly in the design loop. The code has been written in ANSI "C" to be platform independent. CSCMDO has been tested extensively on aerospace configurations. The test cases range from simple wing/body configurations to full HSCT geometry with tail surfaces, engine nacelles, and canards. The code is also used outside the design loop in the GEOLAB for rapid modification and quality checks of existing CFD volume grids.

## **A.7 GridTool**

GridTool is an interactive program for IRIS workstations. This program has been developed for unstructured and structured grids. In unstructured areas, the code is capable of generating an input file for VGRID systems. Surfaces can be read either in point form such as GRIDGEN, PLOT3D, LaWGS, etc., or NURBS form such as IGES-128. Then, the surfaces are represented internally as NURBS surfaces. Also, the code can be used to project either unstructured or structured surface grids onto NURBS surfaces. There is a batch version available for projecting unstructured and structured surface grids.

## A.8 SCAFFOLD

SCAFFOLD is an interactive program that allows surfaces to be constructed from a group of points, such as surface measurements from a laser digitizer or cordax machine. The program accepts x, y, and z point values in the following formats: ECHO (laser digitizer), LaWGS, PLOT3D, and GRIDGEN. A new surface is created first by defining the points along the surface edge by selecting existing points. From the edge points, four edges are specified by selecting four corner points. An  $m \times n$  mesh is defined by bilinearly interpolating points along the edges and in the interior of the new surface. The mesh is then projected onto the point sample using a normal projection algorithm to obtain the curvature of the original sample. The program also includes other tools to aid in surface development such as surface shading, displaying surface normals, and interactive means to rotate and translate surfaces.

SCAFFOLD is coded in the C programming language and runs on Silicon Graphics Iris workstations. The code is still under development with most of the effort concentrated on automating the process described above. Currently, work is being directed toward developing methods to extract geometry and topology from a group of points to form mathematically represented surfaces. SCAFFOLD is a simple solution to this problem since it provides the tools necessary to develop surfaces that can be manipulated by existing CAD/CAM packages, but it requires heavy user interaction and user knowledge of the topology represented by the sample points. More sophisticated algorithms can be easily incorporated into SCAFFOLD as they become available.

## A.9 SurfACe

A Surface Analysis Code (SurfACe) has been developed to help researchers assess surface grid quality of computational grids used in CFD analyses. Anomalies in grids used in these analyses can result in flow solutions that are not consistent with the true flow field characteristics of the vehicle. SurfACe can be used to highlight grid generation errors that are not easily detected in wireframe or shaded representations of a grid and thereby can increase the cost effectiveness of CFD as a design tool.

SurfACe can be used to evaluate both structured and unstructured surface grids on a number of grid quality parameters that indicate changes in surface curvature and changes in surface grid quality. Surface curvature parameters included related to grid smoothness are: the magnitudes of the x-, y-, and z-components of the surface normal vectors, first and second derivatives of these vectors, and the normal, Gaussian, and mean curvatures. Grid quality parameters included related to grid resolution are: surface grid cell area, orthogonality, and aspect ratio. Each parameter is displayed on the geometry using a variable color map. The displays can be viewed dynamically with rotation, translation, and scaling being controlled either by the keyboard or by the mouse. Wireframe, hidden line, and shaded views of the surface grid are also available.

## **A.10 VOLUME**

VOLUME is an interactive program written for IRIS workstations to generate multi-block structured volume grids. The code reads the surfaces of each block in either GRIDGEN or PLOT3D format. A transfinite method is used with the following blending functions: (1) Soni, (2) exponential, and (3) natural log. The unique feature of this program is the capability of not only specifying the boundary surfaces of each block but also the internal surfaces.

## **A.11 VGRID/USM3D**

The VGRID/USM3D aerodynamic analysis system is available for computing the flow-fields around complex configurations. VGRID is a robust, user-oriented code for generating unstructured tetrahedral grids around very complex geometries by the Advancing Front Method. USM3D is an upwind flow code for solving the Euler equations on tetrahedral grids. Input for the system is facilitated through the GridTool utility developed by CSC Corporation and available through GEOLAB. The system is widely used and is supported by the Transonic Aerodynamics Branch (Contact: Dr. Neal Frink/804-864-2864).

## **A.12 TLNS3DMB and CFL3D**

Two Reynolds-Averaged Navier-Stokes solvers developed in the Computational Fluid Dynamics Laboratory (B1192) are available for computations on block-structured grids. The two codes, TLNS3DMB and CFL3D, can and have been used extensively for a variety of applications across the Mach number range. The features of the two codes are:

Steady and unsteady strong conservation law forms of compressible flows

Finite-volume discretizations

Euler and Navier-Stokes (laminar and Reynolds-averaged) solvers

Second-order spatial accuracy

Range of turbulence models from algebraic to two-equation models

Full MultiGrid (FMG) acceleration, including grid sequencing, to steady state

Perfect gas equation of state

The TLNS3DMB code has evolved from central-differencing concepts for the convective and pressure terms while the CFL3D code has evolved from upwind-differencing concepts. Both codes treat the viscous terms with central differencing. Either code allows an arbitrary

number of generalized coordinate blocks. The CFL3D code has generalized patched and overset grid capabilities while TLNS3DMB requires a one-to-one connection between the grid points of the blocks. A unified input and output format is currently being developed and tested for both codes. Contact: Dr. Chris Rumsey (804-864-2165) for CFL3D and Dr. Veer Vatsa (804-864-2236) for TLNS3DMB.